A-TRAIN SYMPOSIUM
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Biomass Burning Plume Injection Height Estimates using CALIOP, MODIS and the NASA Langley Back Trajectory Model.

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Photo courtesy of Brian Stocks

Motivation

Smoke from biomass burning contributes to:

- ❖ **Decreased visibility - increased regional haze in protected areas;**
- ❖ **Major contributor of particulate matter (PM), ozone, NOx, VOCs and other pollutants;**
- ❖ **Impedes the ability of regions to achieve National Ambient Air Quality Standards (NAAQS) for PM 2.5 and ozone;**
- ❖ **Alters the Earth's radiation balance and feedback to climate change (i.e. cloud formation, patterns of precipitation, vegetation change, black carbon on snow and ice).**

Fire Plume Injection Height

is important to fully assess.

If we don't get the injection height correct, the transport of pollutants will be incorrectly modeled resulting in:

* a mis-informed public (air quality reports), which could adversely affect human health;

* an inability to accurately assess the Exceptional Events Rule (72 FR 13560, March 22, 2007), which allows the exemption of certain monitored data that are affected by natural exceptional events from consideration when determining a State's NAAQS compliance; and

* inaccurate tracking of elemental carbon, which could be transported to the Arctic, potentially having a strong influence on the climate system.

This work serves as an example of the capacity of A-train data (CALIOP, MODIS and GEOS-5) to inform both Science and Applications.

Objectives of this talk

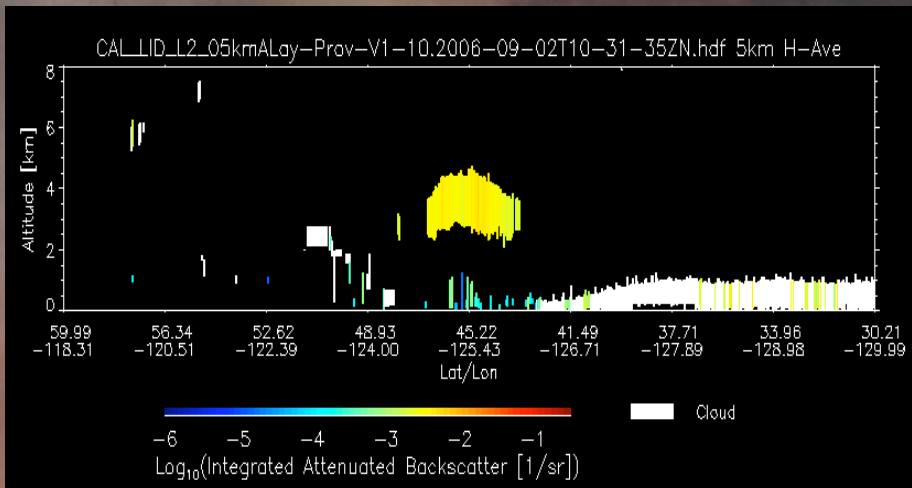
I Introduce the methodology used to generate a fire plume injection height database using a combination of A-train data (CALIOP, MODIS and GEOS-5).

II Seek Audience Feedback

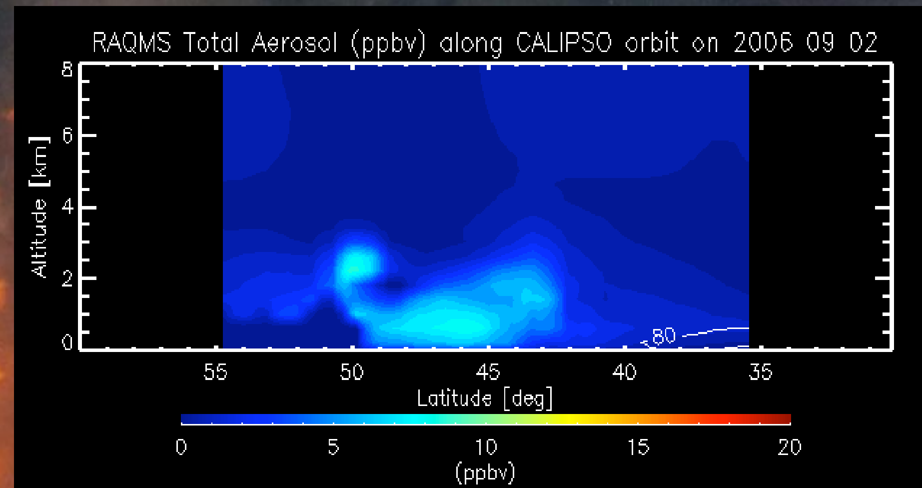
Together with existing A-train MISR plume height data, we can inform the current understanding and modeling of fire plume injection height.

Example of the Problem

CALIPSO plume height



Chemical transport model



Courtesy of Brad Pierce and Chieko Kittaka

This model underestimates plume height by about 1/3 for this western fire.

If the plume height is incorrect, then the transport of those emissions will be incorrect potentially adversely influencing public health and the Exceptional Events Rule.

Photo courtesy of Brian Stocks

History

Previous plume height has been based on the pioneering work of G.A. Briggs [1969; 1971] and verified with limited field campaign data [Clements et al., 2007].

We have an increasing number of ground-based lidar and aircraft verification measures.

There are currently 2 satellites that can provide the statistics necessary to understand and verify plume height.

I. *MISR - Multi-angle Imaging SpectroRadiometer*

II. *CALIPSO - Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation*

CALIPSO

** able to identify plume heights from extensive smoke fields;*

** increased capability of detecting optically thin smoke layers at a finer vertical resolution;*

** smoke plume identification with back trajectories are temporally random, representing the entire temporal range of fire plumes.*

MISR

** needs abrupt well-defined columns - relies on multi-view angles to estimate the stereo height of distinct features;*

** substantially larger swath width than CALIPSO which results in a greater opportunity to capture smoke plumes [Kahn et al., 2007]; &*

** morning overpasses do not represent the natural temporal fire pattern.*

Sensor (spacecraft)	Product	Spatial Resolution	Satellite Overpass	Temporal Availability
MISR (Terra)	AOD, aerosol plume height	17.6 x 17.6 km^2	10:30 a.m.	~Once every 7 days
CALIOP (CALIPSO)	extinction profile	100 m diameter x 30 m vertical	1:40 p.m.	Once every 16 days

Fire Regimes Vary Widely

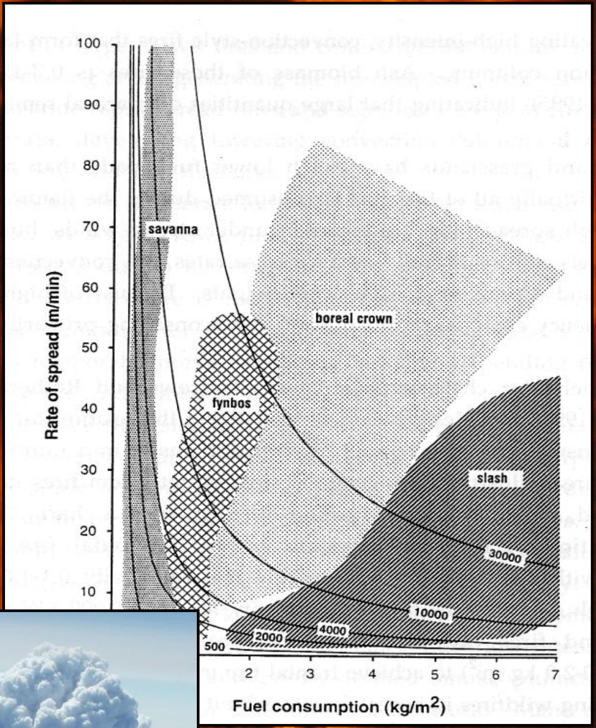
Photos: Stocks and Soja

Fire Intensity/Energy Release

- Combine rate of spread/fuel consumption/heat of combustion to determine fire intensity (I=HWR) = resistance to control

- Savanna Fires:
  - 10-12 t/ha
  - 500-10,000 kW/m
  - Lower convection columns

- Boreal/Temperate Forest Fires:
  - 25-50 t/ha
  - 100-100,000 kW/m
  - > fuel consumption & intensity
  - Towering convection columns reaching UTLS



A typical high-intensity boreal crown fire convection column viewed from an altitude of ~10 km *(photo courtesy Mr. Todo, JAL)*

June 28 2008
Columns near
Lake Athabasca:
5-6 km

Photos courtesy P3 group

Climate → Weather → Available Fuel → Injection height

Fires between Athabasca and Reindeer Lakes

June 30 2008

5-7 km

Photos courtesy P3 group

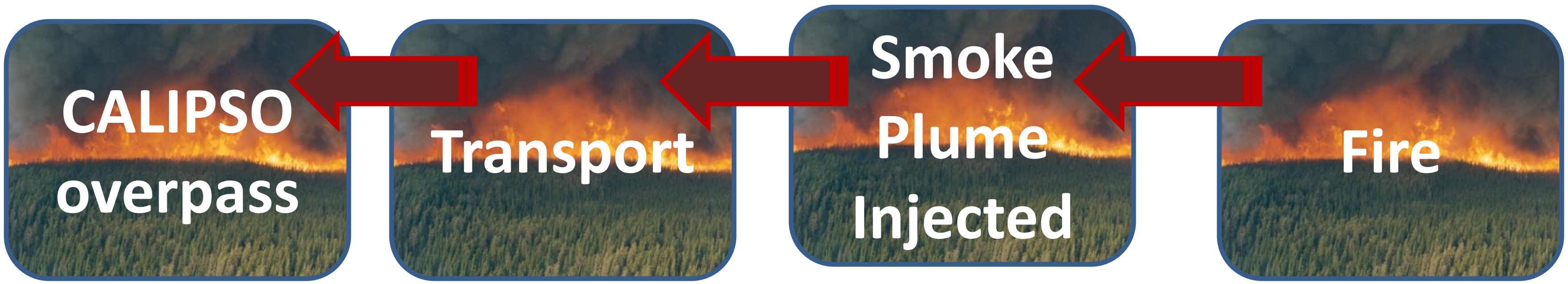
Climate → Weather → Available Fuel → Injection height

Typical pyroCb convection columns (10-12 km)

Typical pyroCb fire behavior: continuous high-intensity crown fires

Climate → Weather → Available Fuel → Injection height

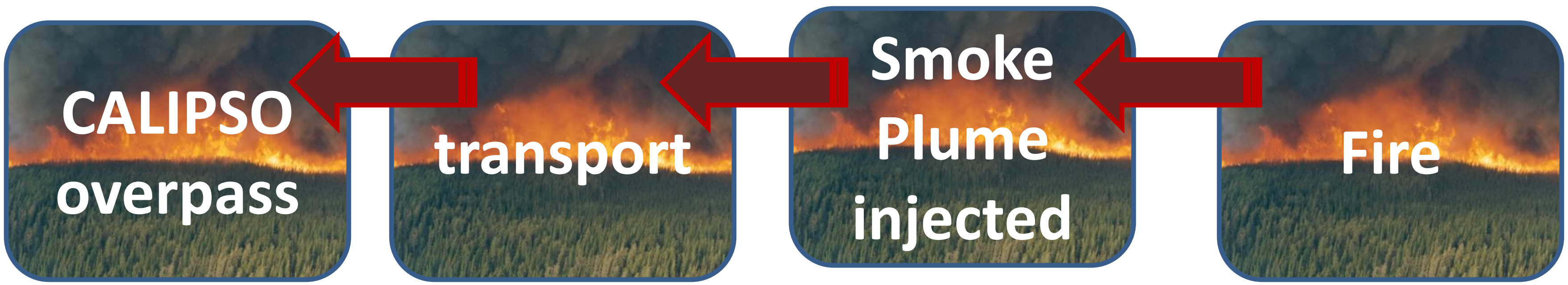
Process



- Coincidence in Calipso and plume;
- LaRC trajectory model to;
- Coincidence with fire detection

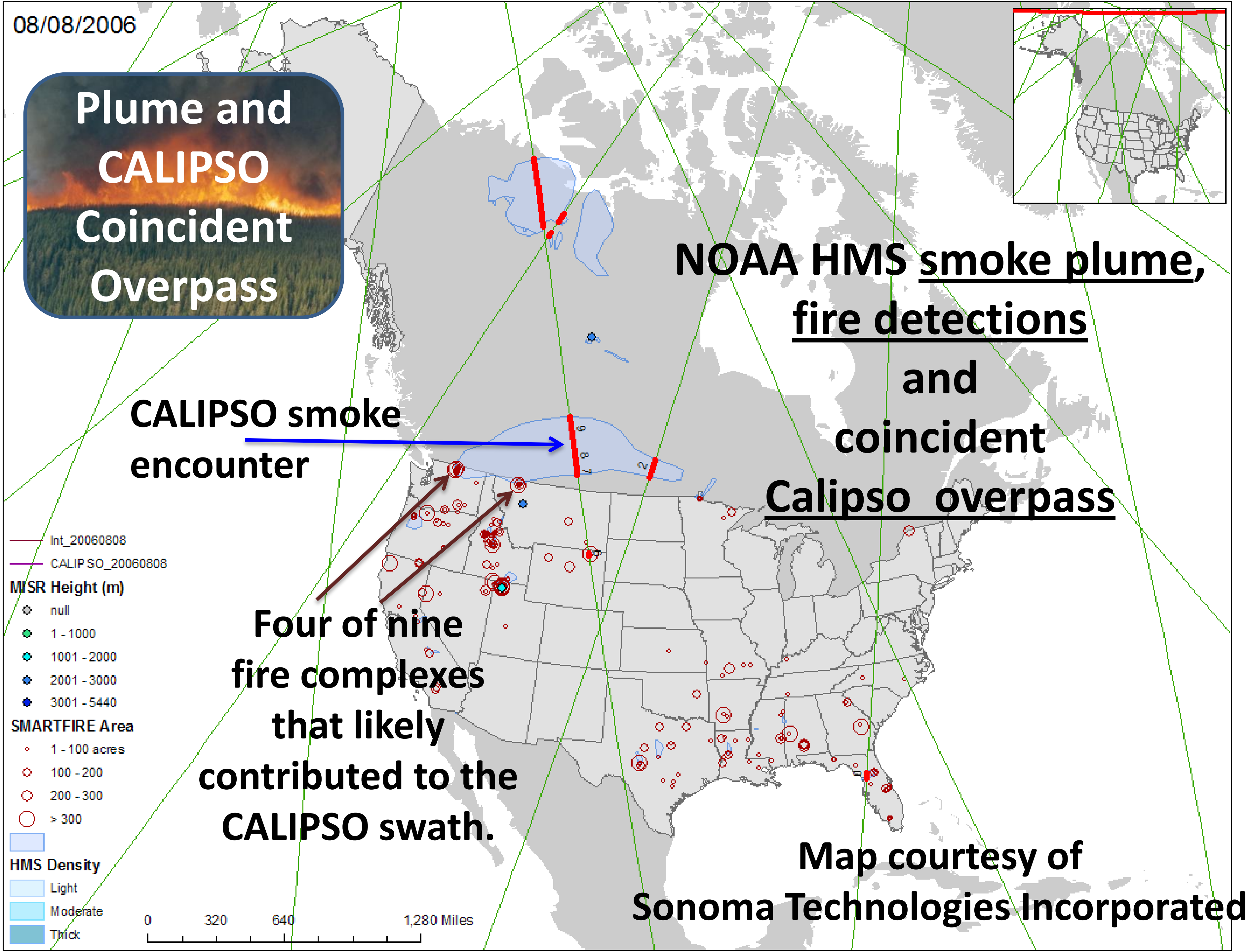
All in 3-dimensional space and time

Current Criteria for Coincidence



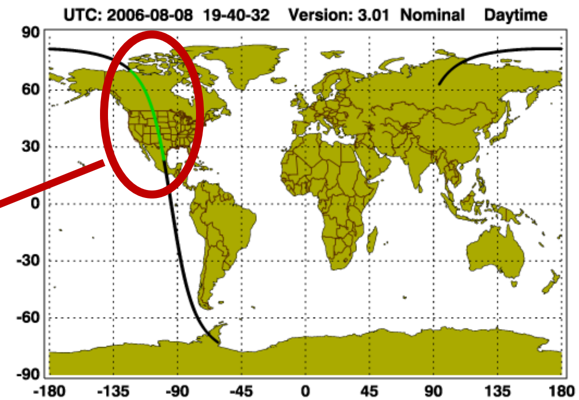
Coincidence Criteria

- ❖ Coincidence between air parcel and fire detection in space (20 km) and time (day)
- ❖ Fire detection > 35% confident
- ❖ If above boundary layer, must be coincident with 10 or more detections

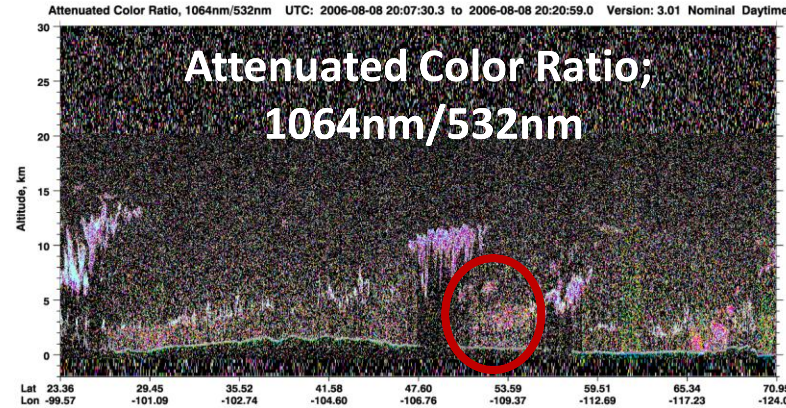


08/08/2006
Plume and CALIPSO Coincident Overpass
NOAA HMS smoke plume, fire detections and coincident Calipso overpass
CALIPSO smoke encounter
Four of nine fire complexes that likely contributed to the CALIPSO swath.
Int_20060808
CALIPSO_20060808
MISR Height (m)
null
1 - 1000
1001 - 2000
2001 - 3000
3001 - 5440
SMARTFIRE Area
1 - 100 acres
100 - 200
200 - 300
> 300
HMS Density
Light
Moderate
Thick
0
320
640
1,280 Miles
Map courtesy of Sonoma Technologies Incorporated

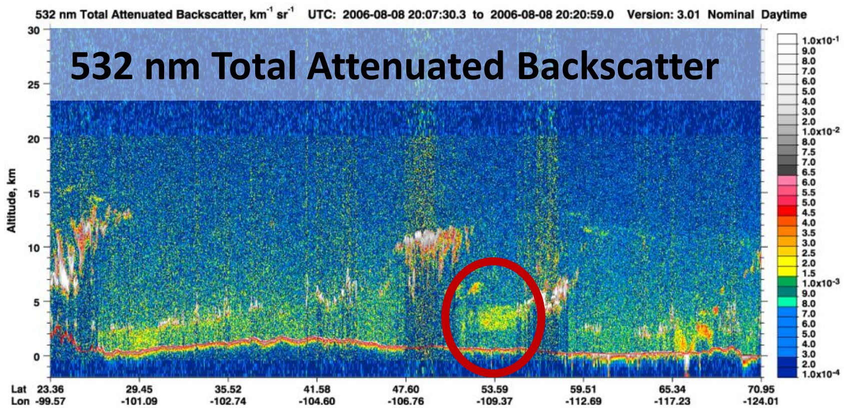
CALIPSO Curtains 08 Aug 2006 (v3)

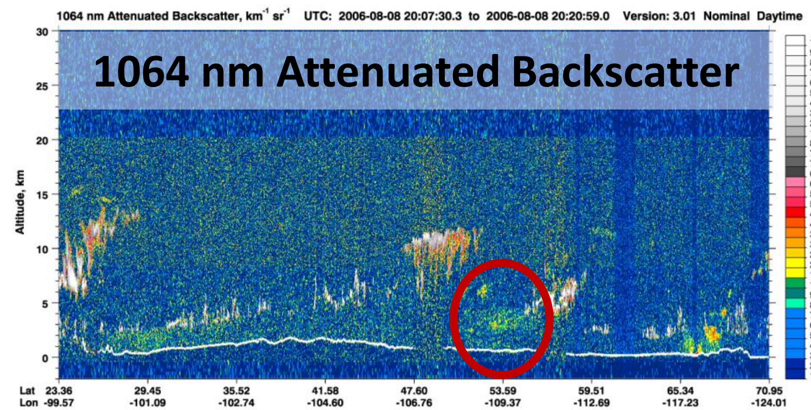


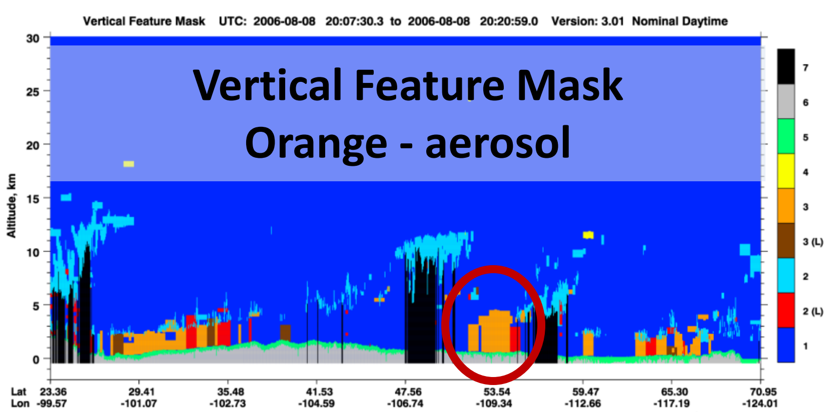
Swath from south to north

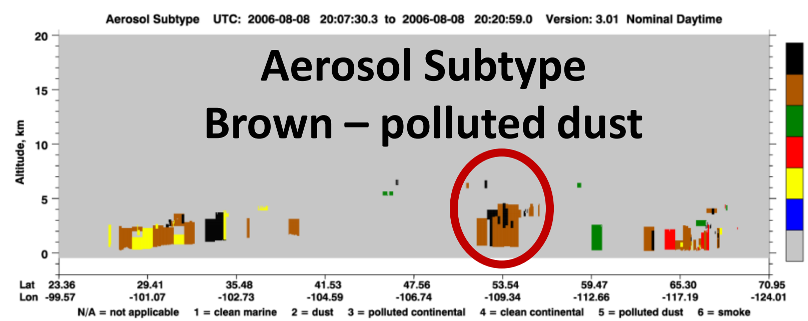


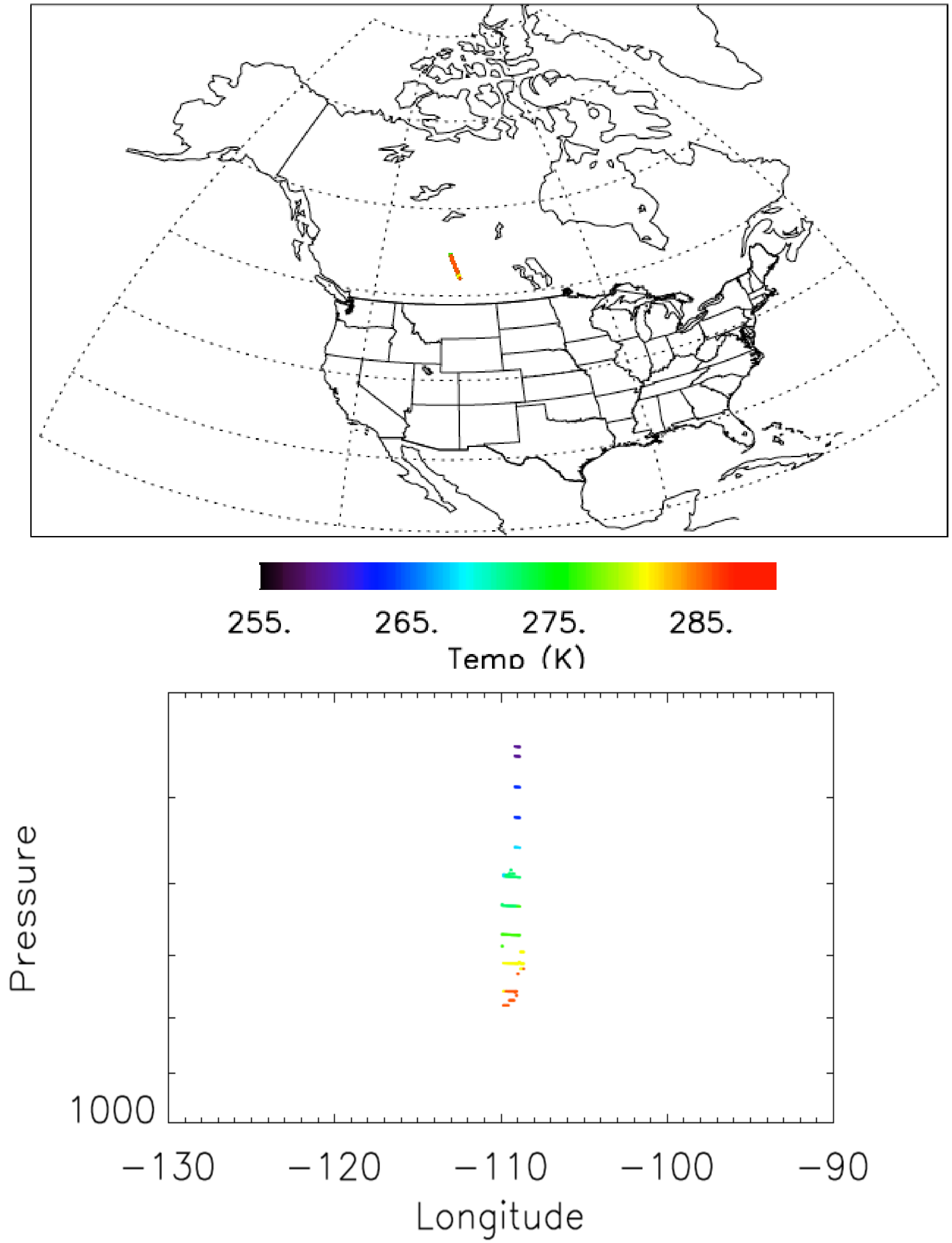
20:07 to 20:20





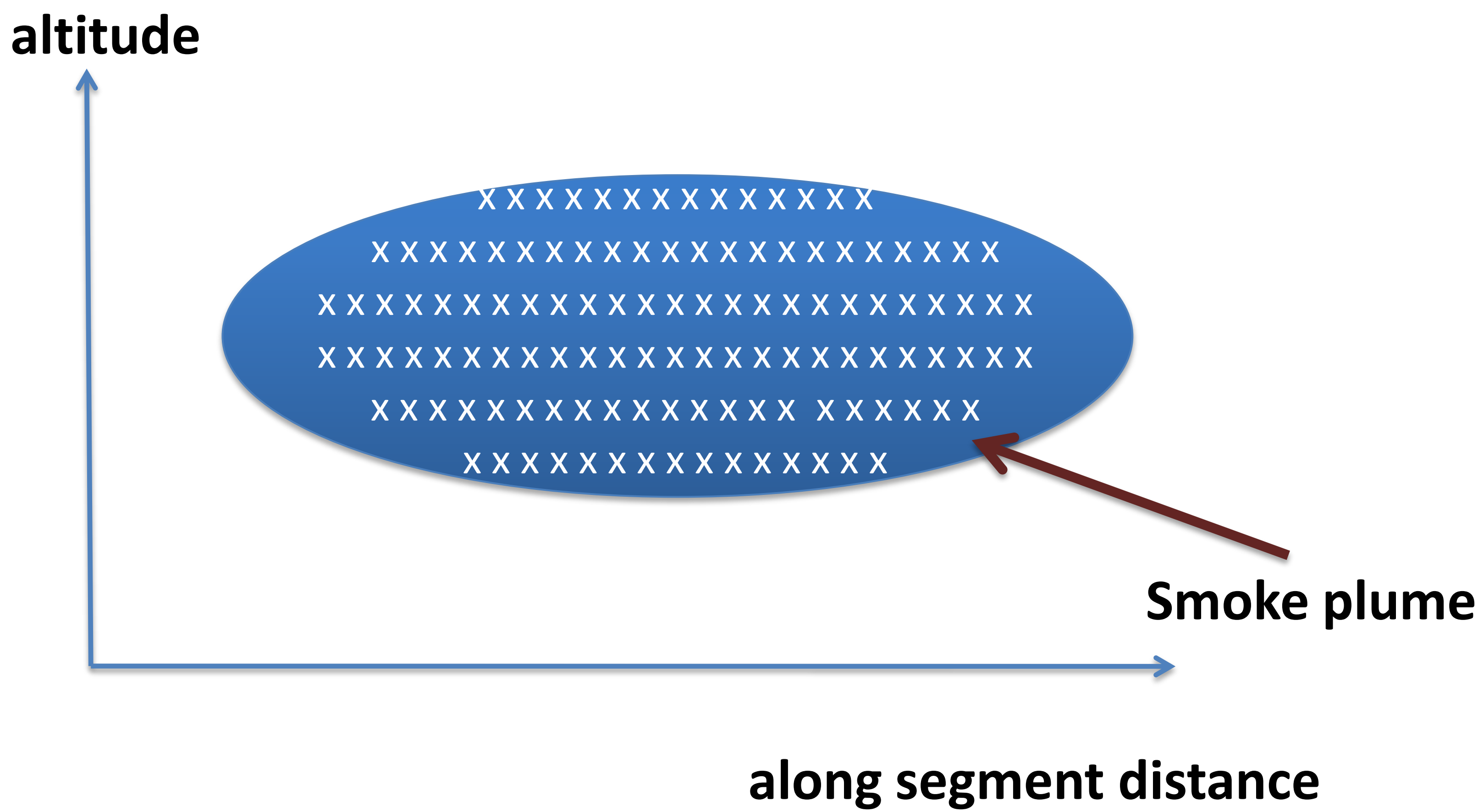


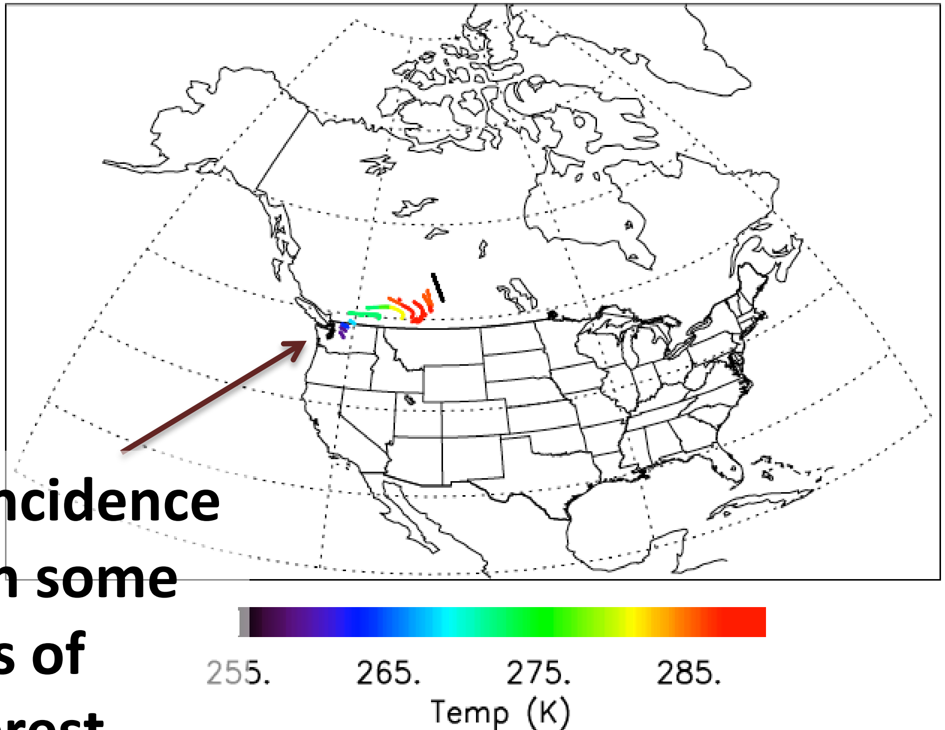




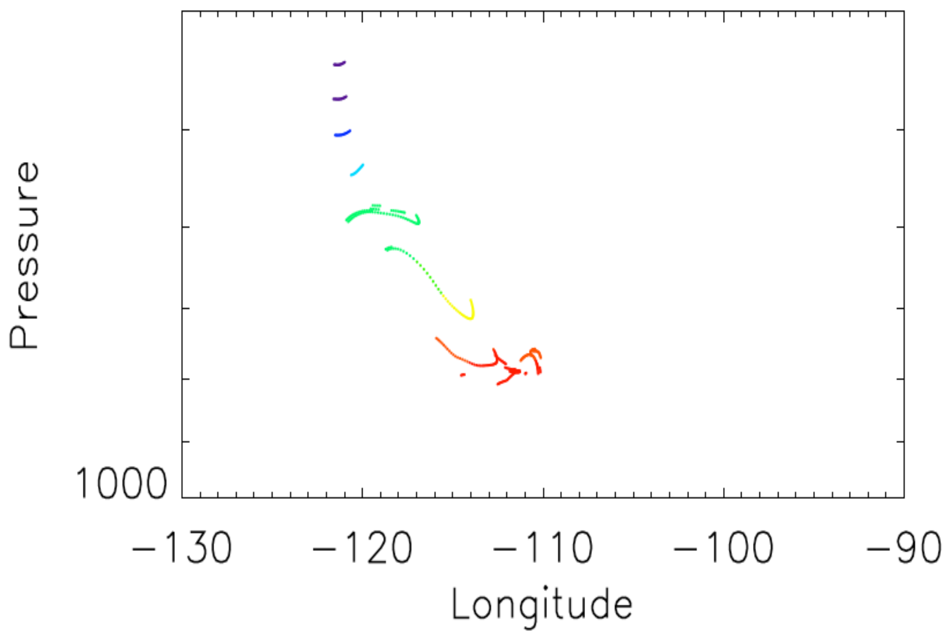
Trajectories are initialized at ~1 second intervals along the CALIPSO smoke segment track and at 500m vertical intervals within the smoke plume. There is a 15 minute trajectory time step.

Schematic of trajectory initialization:
each cross represents an initial parcel location



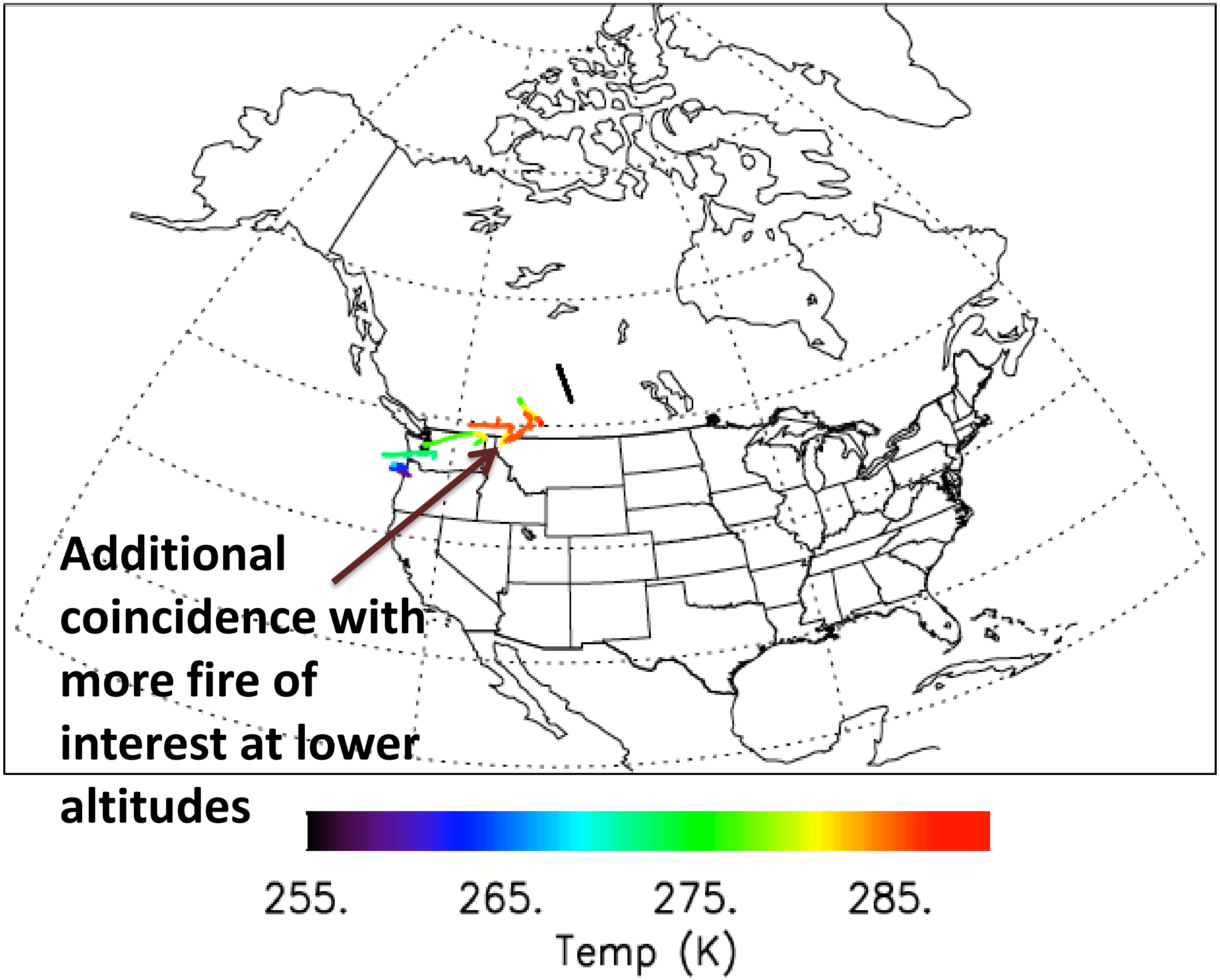


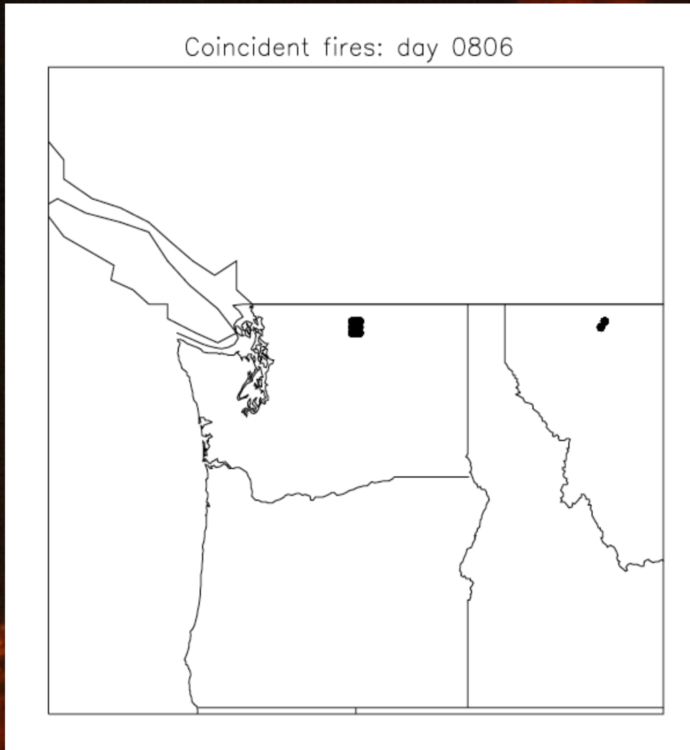
Coincidence with some fires of interest.

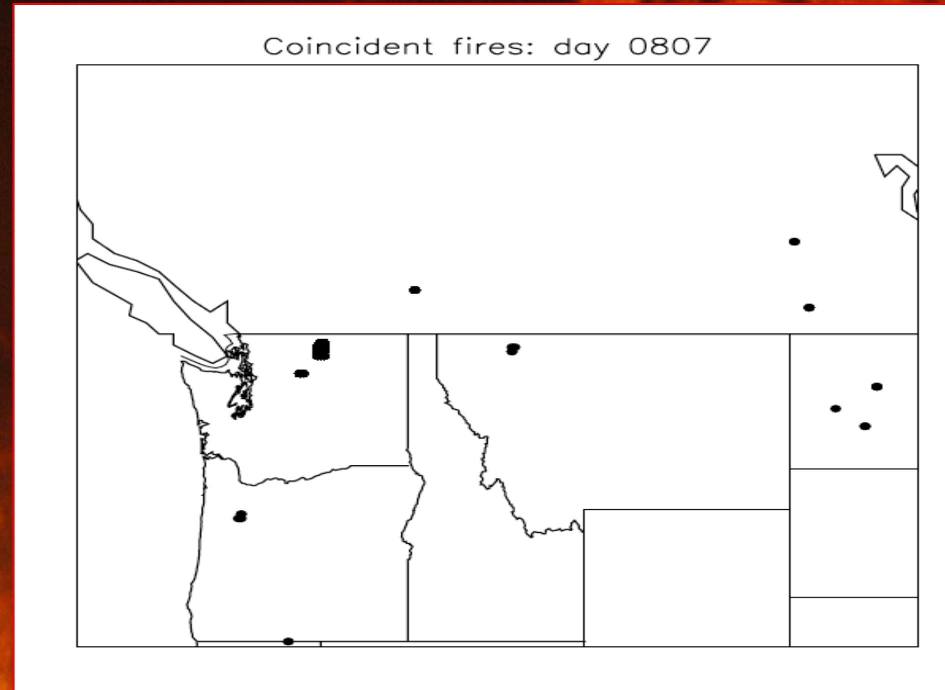


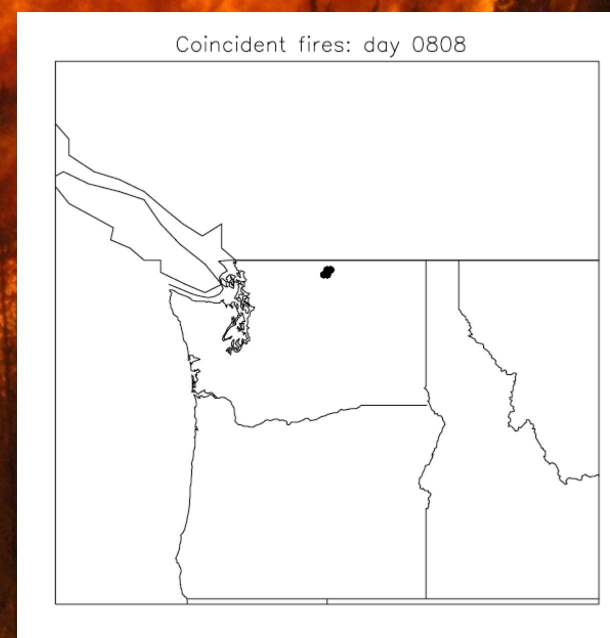
T – 24 hrs: Back trajectories pass over "fire of interest" in North-Central Washington in the mid troposphere (~ 500 mb, ~17000 ft, ~5.2 km).

T – 36 hrs: Back trajectories pass over “fire of interest” in North-West Montana, in the lower trop. (~ 800 mb, ~ 6500 ft, ~ 2 km)









As the air parcel trajectories are traced back in time, each day there are unique coincidences with fires on the ground.

CALIPSO Data and Associated Variables

Active fire size or area burned
(source)
Number of active fire detections
(MODIS Terra and Aqua)
Fire radiative power or energy

CALIPSO curtains
Top, median and bottom of
CALIOP plume height

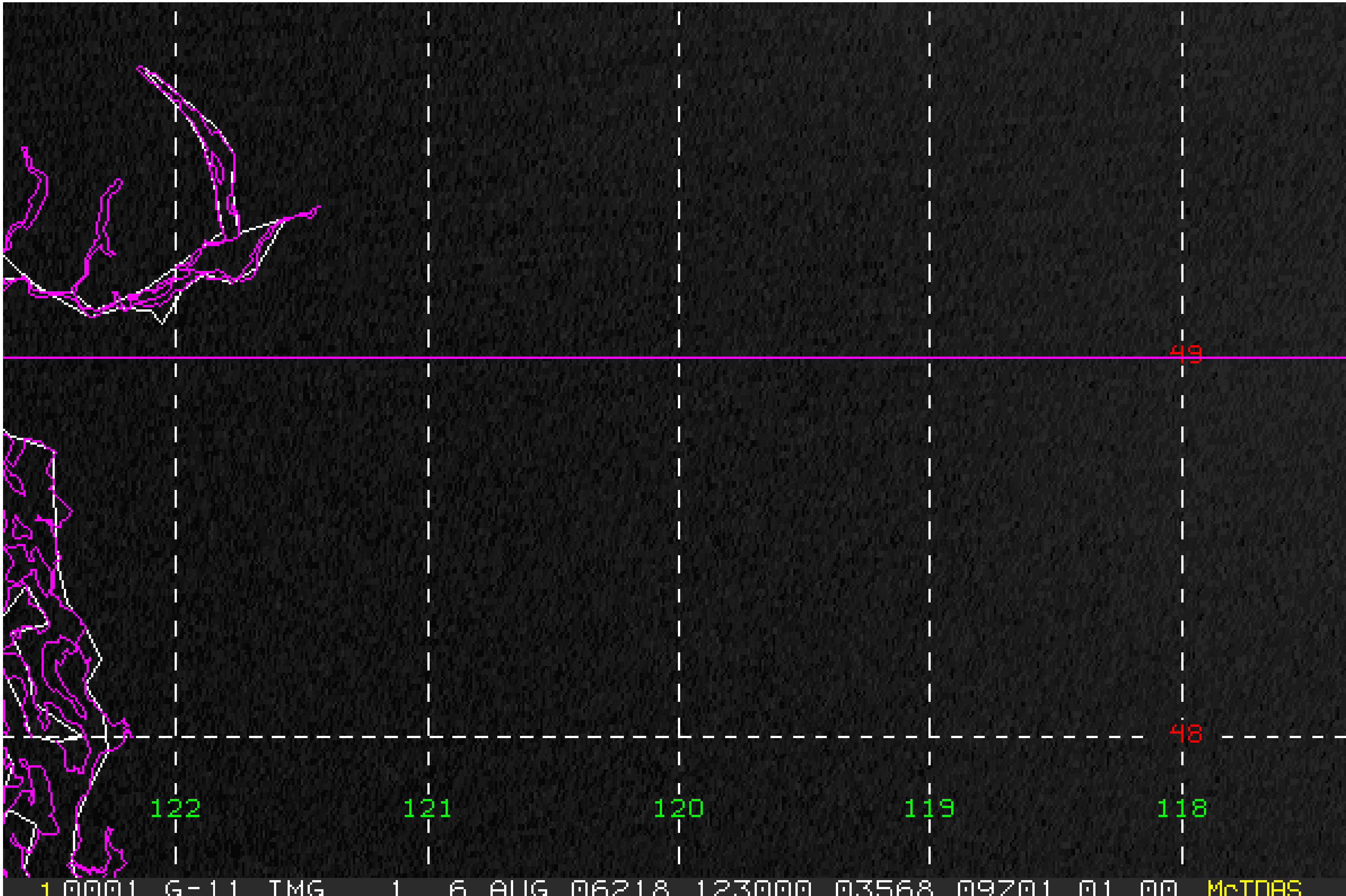
IGBP vegetation 1km MODIS
Elevation
Available fuel

Air parcel counts , mean range

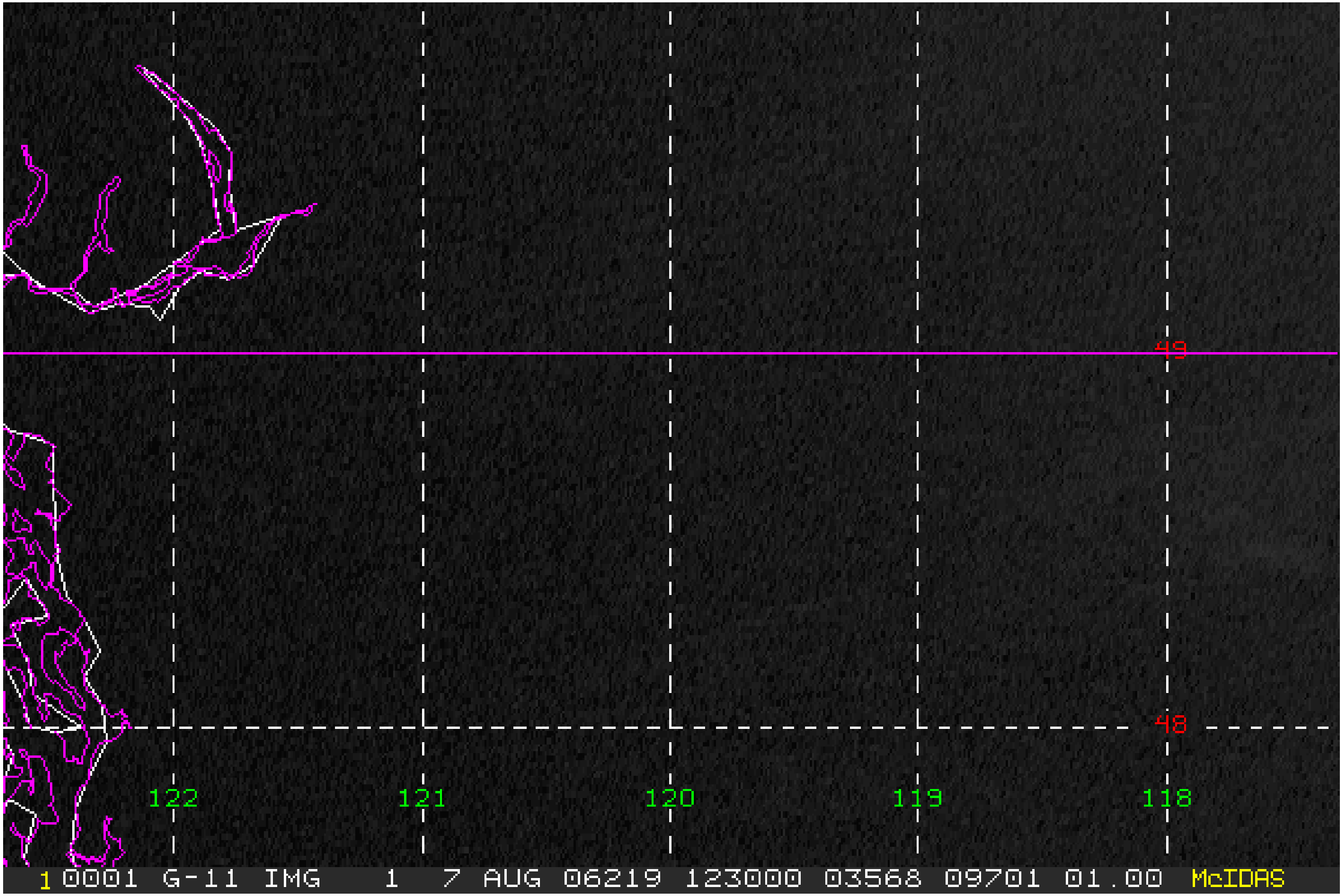
Relative Humidity (2m, 10m)
Temperature (2m, 10m)
Wind speed and direction
Precipitation
Fire weather
(Haines, CFFWIS ?)
Time of day
(solar zenith angle?)
Atmospheric soundings
(radiosonde NWS – normal 0z
12z and fire weather; GOES-5
PBL

Latitude/longitude
fire location and plume
FIPS
Fire name

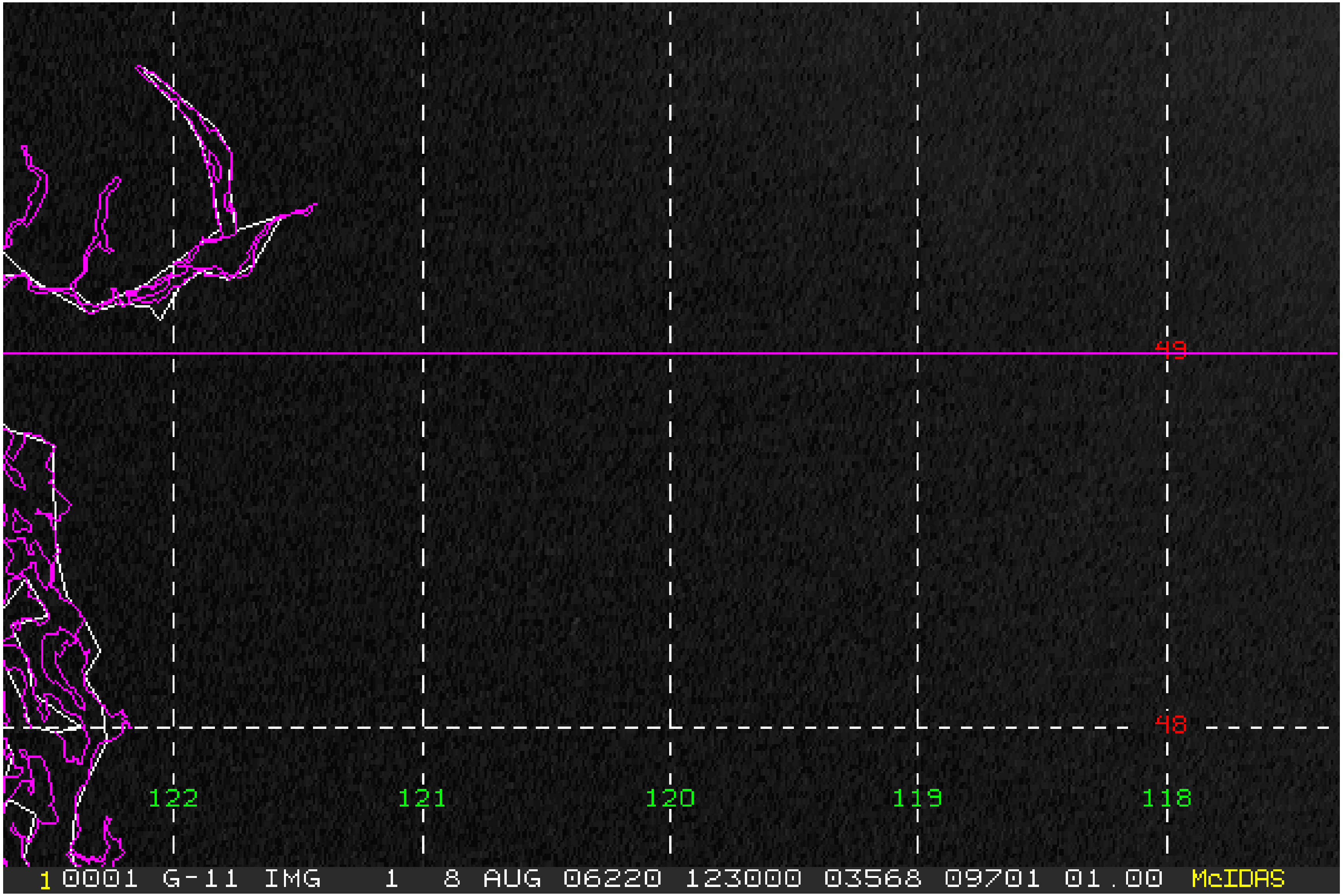
Movie Verification using 15 minute GOES data
August 06, 2006; Two larger fires burning in Washington.



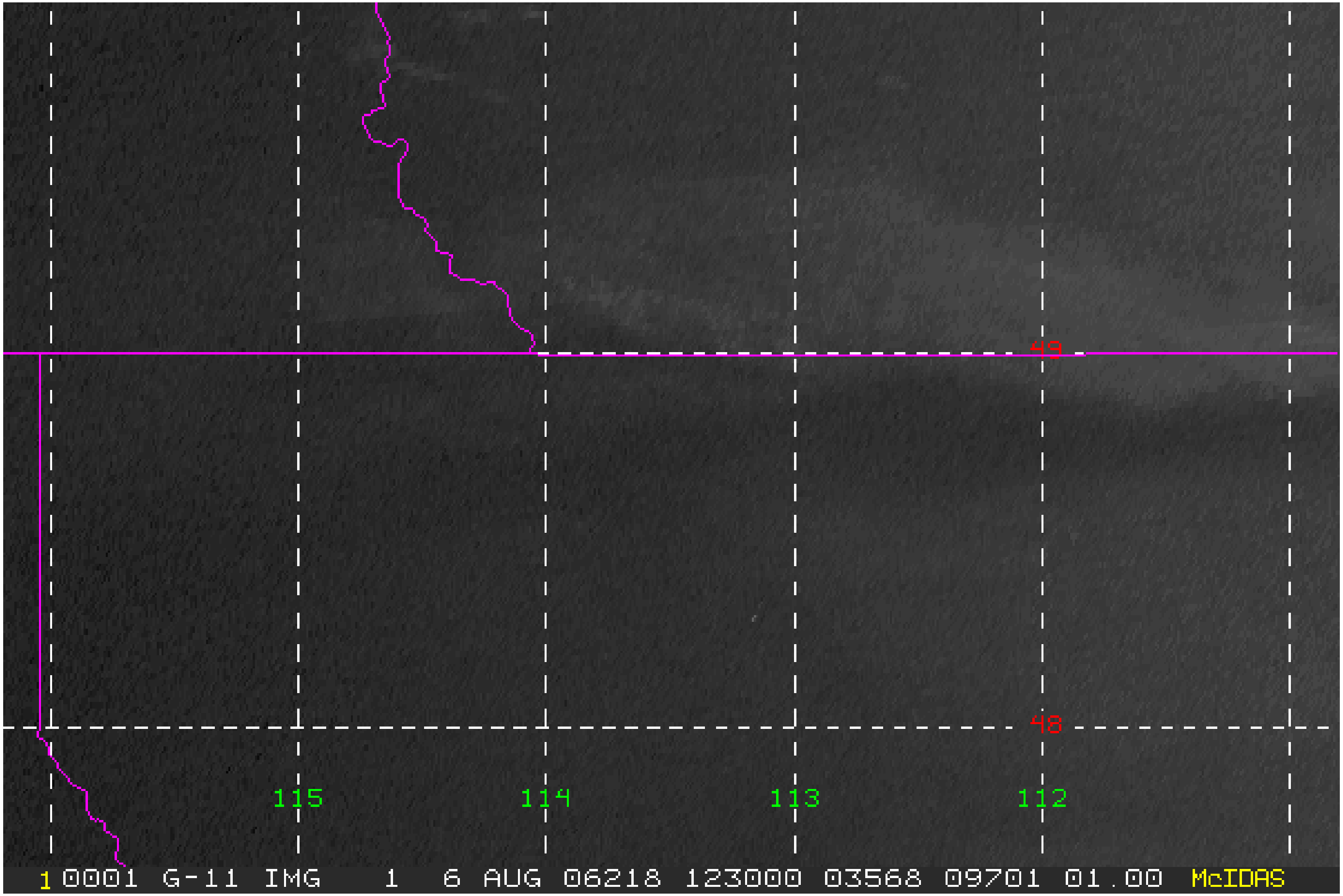
Movie Verification using 15 minute GOES data
August 07, 2006; Two larger fires burning in Washington.



Movie Verification using 15 minute GOES data
August 08, 2006; Two larger fires burning in Washington.

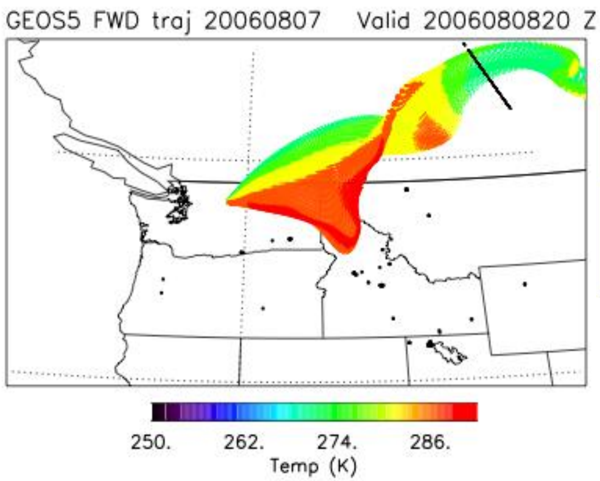


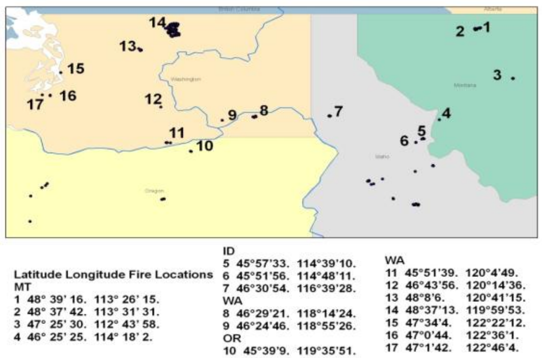
Movie Verification using 15 minute GOES data
August 06, 2006; Two smaller fires burning in Montana.

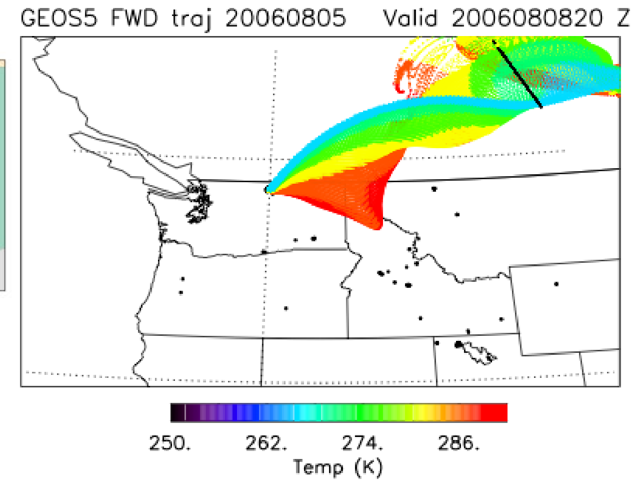


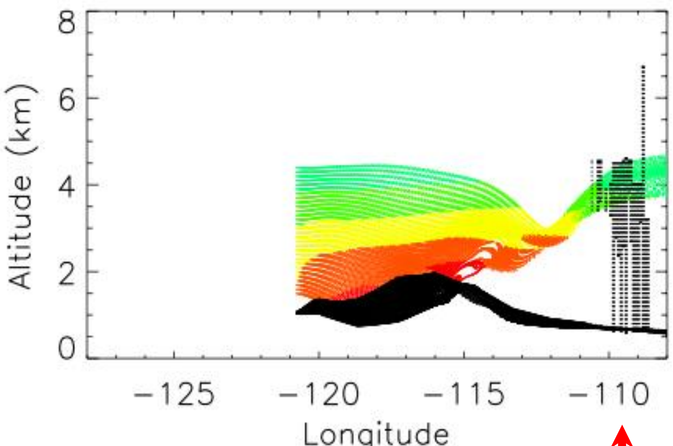
Verification

Forward trajectory from fires in Washington

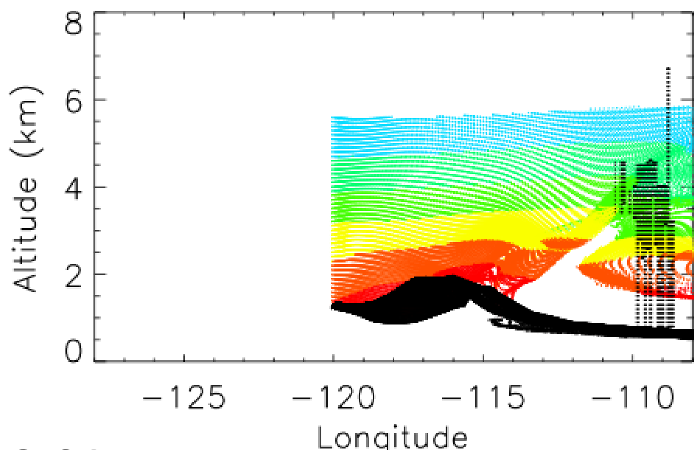








Contribution at a range of altitudes across the entire horizontal swath



CALIPSO Lidar Version 3.01

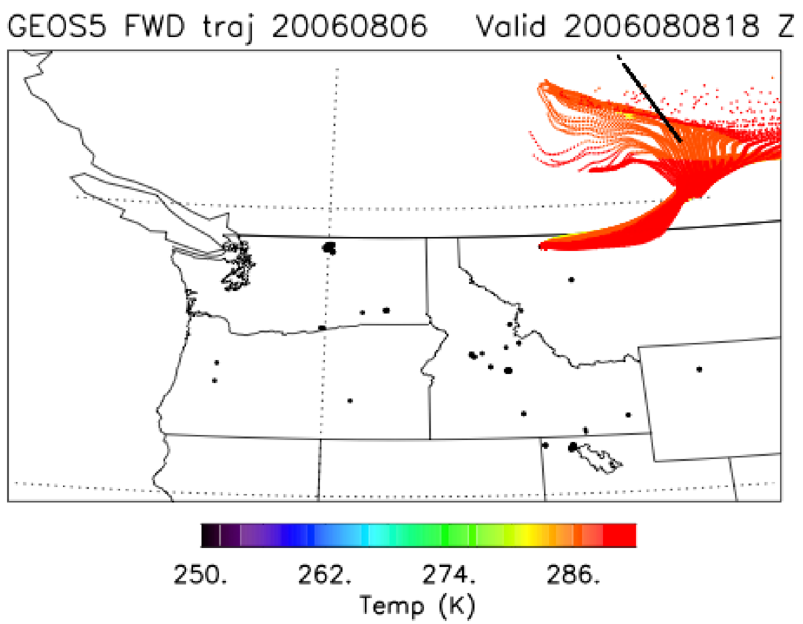
Fire 13, Washington, August 07, 2006

Tripod Fire 14, Washington, August 05, 2006

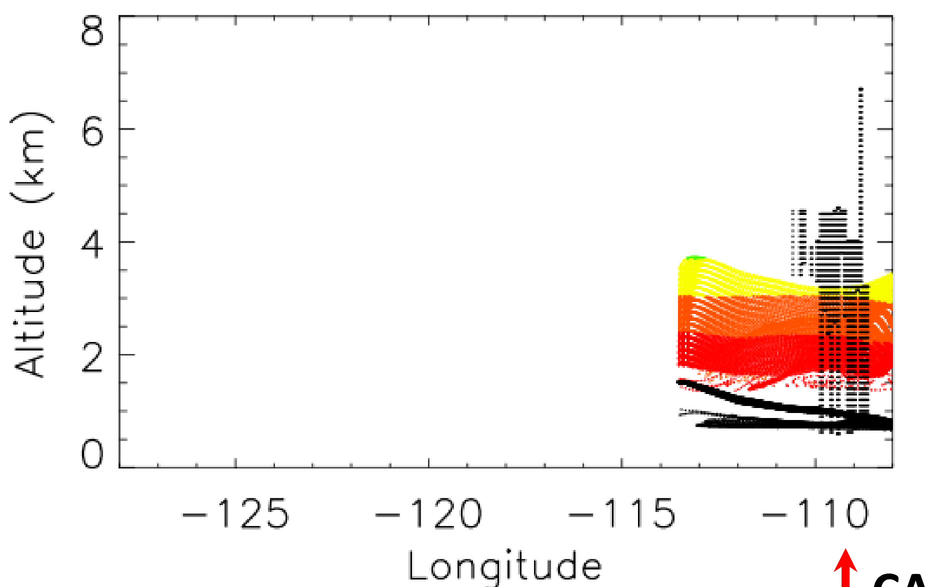
Verification

Forward Trajectory from Montana

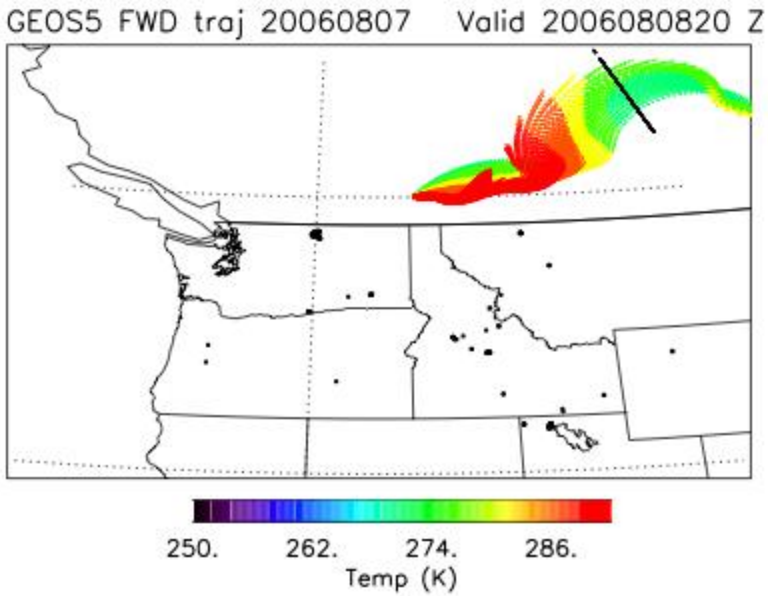
CALIPSO Lidar Version 3.01

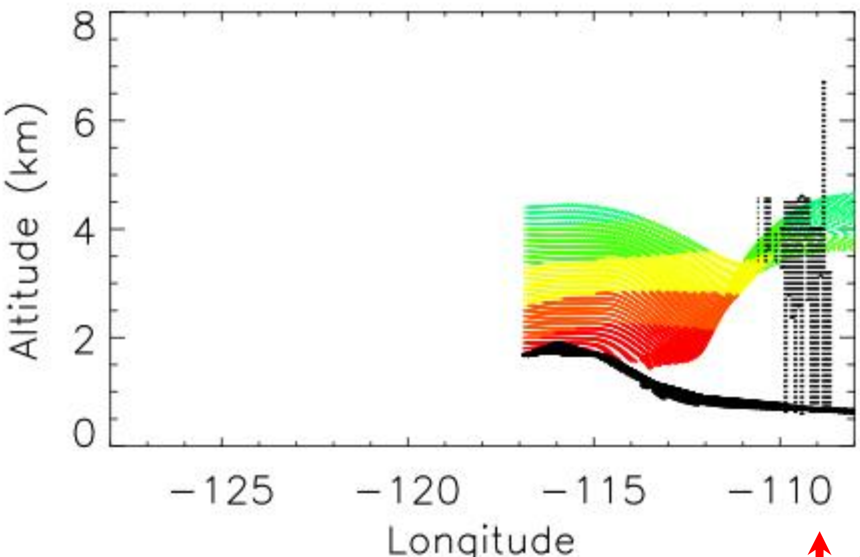


Contributions to the southern section of the overpass at about 1 to 3 km



CALIPSO Lidar Version 3.01





Verification

Forward Trajectory contribution from British Columbia

CALIPSO Lidar Version 3.01

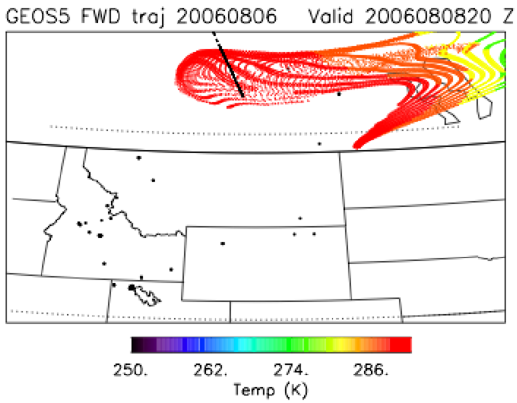
Contribution to mid-altitudes in the mid-range of the overpass.

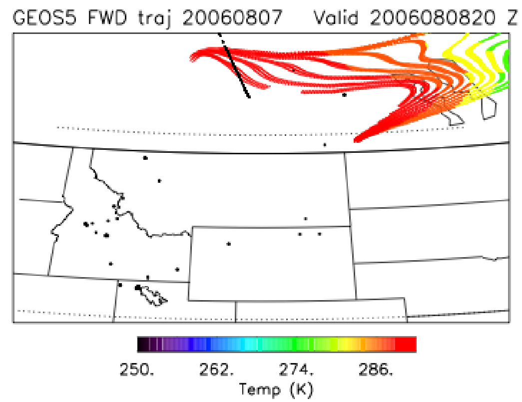
CALIPSO Lidar Version 3.01

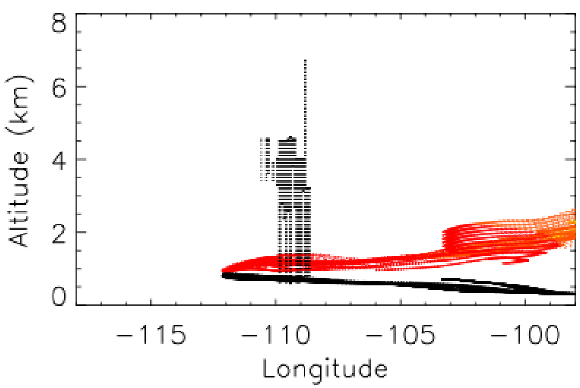
Verification

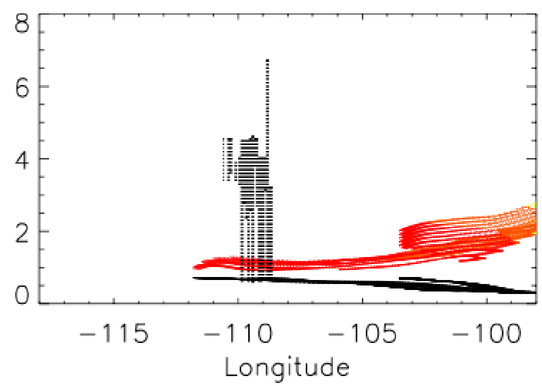
Boundary layer fires from the east

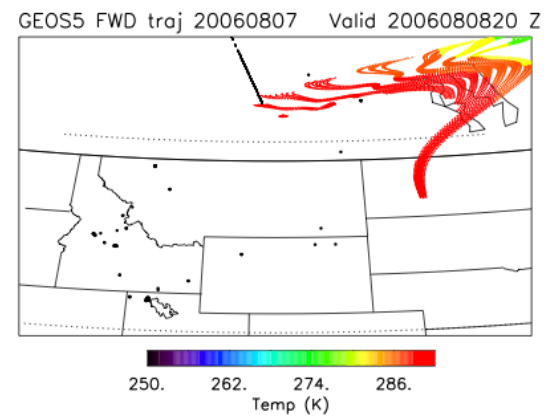
CALIPSO Lidar v3.01



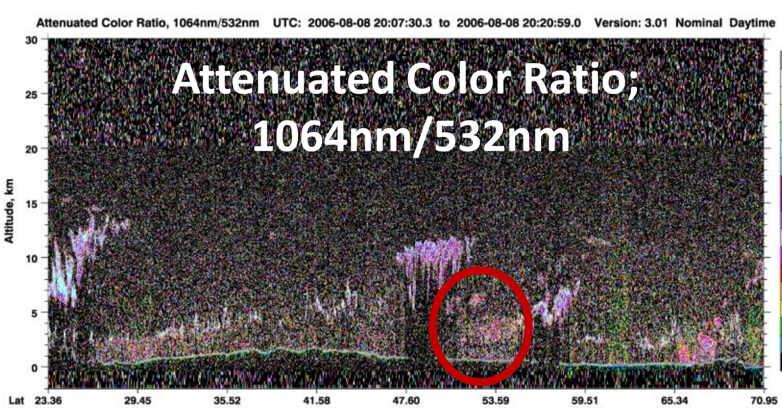


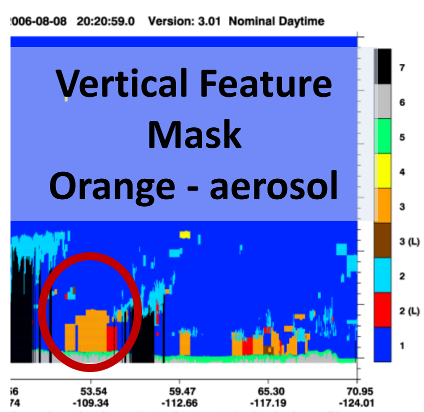


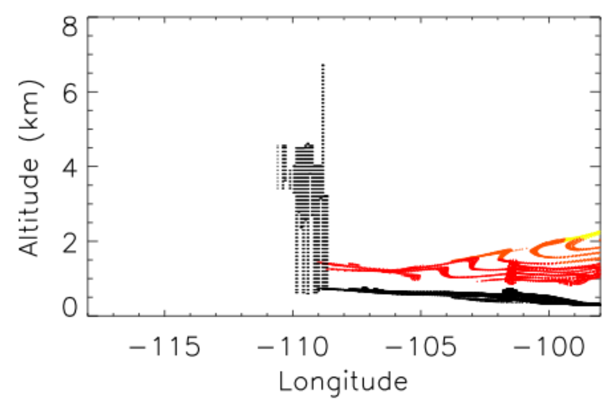




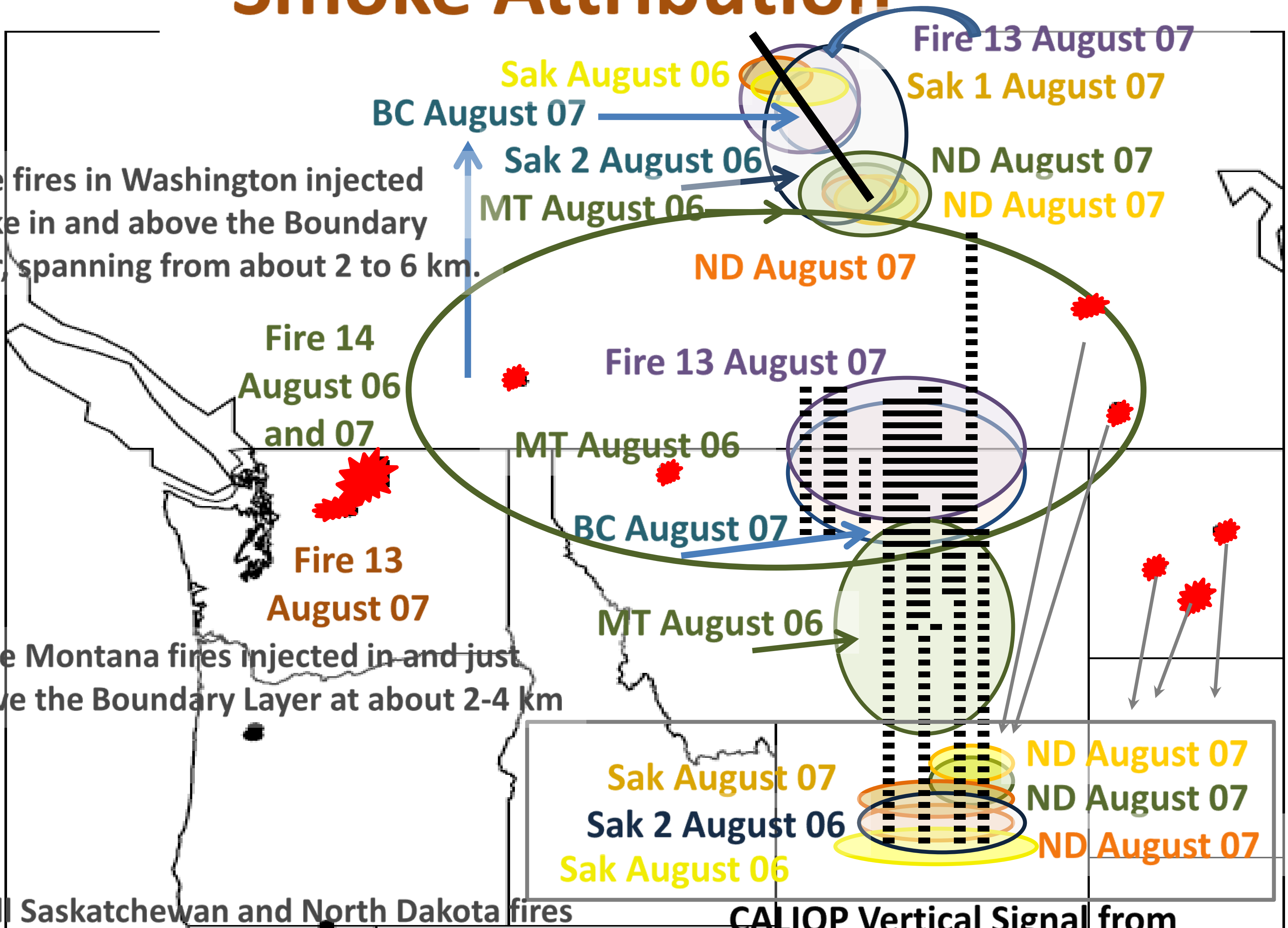
Contribution to altitudes ~1 km and below.







Smoke Attribution



* The fires in Washington injected smoke in and above the Boundary Layer, spanning from about 2 to 6 km.

* The Montana fires injected in and just above the Boundary Layer at about 2-4 km

* All Saskatchewan and North Dakota fires injected in the Boundary Layer at around 1 km

CALIOP Vertical Signal from August 08 2006

This plume can be attributed to 9 separate fires, burning on different days (12 event days):

Washington - large fire

August 6th (~ 3400 m);

August 7th (mean 3300 m, range 1900 – 6300 m);

Washington - medium-sized fire

August 7th (range 2200 – 4400 m)

British Columbia

August 7th about 3400 m

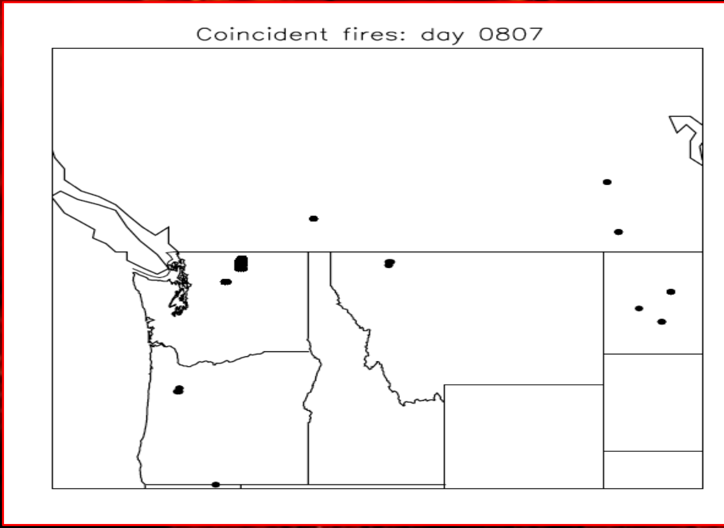
Montana fires – 2 of them

August 6th – mean 1980 m

Saskatchewan (2 fires)

August 6th and 7th ~ 1000 m

North Dakota (2 fires) August 7th ~ 2000 m



Conclusions

- ❖ CALIPSO data provide a spatially and temporally random view of fire plume data, one that is not limited to particular fire types or times of day.

- ❖ One CALIOP swath can be representative of a complicated 3-D temporal and spatial story that incorporates several days, several fire events and a range of fire types from agricultural to large wildfires.

- ❖ In concert, CALIOP and MISR data will add to the statistical knowledge necessary to improve our knowledge of the dynamics of fire plume injection height.

Thanks!

to the Environmental Protection Agency;
the CALIPSO Team specifically
Dave Winker, Mark Vaughn, Chip Trepte and Ali Omar;
the ARCTAS/ARCPAC science teams;
the NOAA HMS team;
Brian Stocks; Mike Fromm; Sean Raffuse; and

a NASA funded Air Quality Applications Project:

Linking NASA Satellite Data and Science to Enhance Fire Emissions within the EPA's National Emissions Inventory: Developing Agricultural/Rangeland Fire Emissions Estimates, Connecting Models to Plume Injection Height Data, and Verifying Modeled Emissions Estimates

Co-Investigators: Jassim Al-Saadi, T. Duncan Fairlie, Nancy H. F. French, Joe Kordzi, Jessica McCarty, Tom Pace, Tom Pierce, George Pouliot, James Szykman and David Westberg

Collaborators: Richard Ferrare, Louis Giglio, Scott Goodrick, Ralph Kahn, Chris Schmidt, Shawn Urbanski, Tom Moore, Sean Raffuse, Mike Fromm, Brian Stocks and Charles R. Trepe.

Questions ?

Suggestions for additional data ?

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Photo courtesy of Brian Stocks